Gas exchange of *Rhodiola sachalinensis* transplanted from different habitats in Changbai Mountain[1)]

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Abstract *Rhodiola sachalinensis* growing in the different habitats, Xiaotianchi plot (altitude 1 800 m), Tree line plot (altitude 2 000 m) and Tianwenfeng plot (altitude 2 325 m), of Changbai Mountain (northern slop) were transplanted to Harbin Experimental Forest Farm for measuring its characteristic of gas exchange. The study results indicated that the growth state and gas exchange characteristics of *Rh. sachalinensis* growing in different habitats varied markedly. The plants transplanted from Tianwenfeng plot had the highest values in net photosynthesis rate (Pn) and transpiration rate (Tr), those transplanted from Tree line plot shows the second, and those transplanted rom Xiaotianchi plot had the lowest values. The variance existed in transplanted plants was the same as shown in the field. From the result it can be extrapolated that the difference of Pn and Tr existed in *Rh. sachalinensis* transplanted from different habitats is depend not only on the environmental factors, but on the variance of physiological characteristic of plant itself.

Key words: *Rhodiola sachalinensis*, Transplanted, Gas exchange.

Introduction [1]

Rhodiola sachalinensis A. Bor, a perennial, medical herb, mainly distributes in Japan, Korea, China and Russia. In China, it mainly distributes in Changbai Mountain, Jilin Province, and Zhangguangcai Mountain, Heilongjiang Province. This typical alpine plant generally distributed in high Mountain, at altitude 1 700~2 500 m (Wu *et al* 1987; Qin 1994; Lu *et al* 1995). *Rhodiola* plant (*Rhodiola rosea* chiefly in Russia) has been extensively studied by scholars from Russia, Ukraine, Japan and China since the 1950's (Ming 1988; Kir'yanov *et al* 1991; Ohba and Midorikawa 1991; Stasyperova *et al* 1993; Wang 1994; Amano *et al* 1995; Bocharova *et al* 1995; Xu 1998). But there are few studies on physiological ecology of *Rh. Sachalinensis*.

We studied gas exchange of *Rh. Sachalinensis* in the field in north slop of Changbai Mountain, southeastern Jilin. The results showed that the characteristics of the plant on gas exchange varied markedly in different habitats and the growth status of the plant also varies greatly (Yan *et al.* 1999). When *Rh. sachalinensis* was transplanted to the same growth environment to cultivate for a short time, after sprouting renewably, the plant showed a similar trend in growth. In order to find out that under the uniformity conditions of growth environment the differences in physiological metabolism disappears or not, we transplanted *Rh. Sachalinensis* from different habitats in north slop of Changbai Mountain to Harbin Experimental Forest Farm and measured the gas exchange in the same conditions.

Materials and methods

Materials cultivation after transplanted

In the preamble work, we selected three plots in north slop of Changbai Mountain, Xiaotianchi (altitude 1 800 m), Tree line (altitude 2 000 m), and Tianwenfeng (altitude 2 325 m), and measured the gas exchange of *Rh. sachalinensis* in the field (Yan *et al* 1999). The healthy and typical individuals of *Rh. sachalinensis* in three plots were transplanted to Harbin Experimental Forest Farm and cultivated in the same conditions. The above-ground part of the plant died after transplanted. New leaves and shoots sprouted after a short time. The plants that grew well were selected and transplanted to the pots (3 plants each pot) and managed routinely for gas exchange measurement.

Measurement of gas exchange

Gas exchange of *Rh. sachalinensis* was measured with a LI-6400 Portable Photosynthesis System (LI-COR Inc., USA). The single leaf of the plant is too small to be measured, so whole twig was put into the leaf-chamber and let the leaves facing to light for measurement. Leaf area was measured with a LI-3000A leaf area meter (LI-COR Inc., USA), and the data were input to LI-6400 Portable Photosynthesis System for recalculating net photosynthesis rate (Pn),

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transpiration rate (Tr) and other relative indexes. Respiration rate (Res) equals to the negative value of measured Pn when the leaf-chamber was covered with a piece of black cloth. So Res here is a respiration rate in day under dark, not a real respiration rate at night.

Curve of light dependent Pn was measured with LED light resource of LI-6400 Portable Photosynthesis System. Initial slope of curve of light dependent Pn was used as apparent quantum yield (AQY, mmol CO_2·mol^{-1} photons). The ratio of Pn to Tr was used as water use efficiency (WUE, mmol CO_2·mol$^{-1}H_2O$), which means CO_2 assimilation quantity with unit quantity water transpiration.

Gas exchange was measured on sunny days. 3 plants were chosen for each measurement and three repeats were made.

Measurement of chlorophyll content

Chlorophyll content was measured according to method of Arnon (1949).

Results and analysis

Photosynthetic characteristic

Measurement begin from 7:00 am to 6:00 pm. Photosynthesis rate measured with LI-4600 Portable Photosynthesis System is net photosynthesis rate (Pn), or the difference between gross photosynthesis rate and respiration rate, and can be also called apparent photosynthesis rate. The result shows that the *Rh. sachalinensis* transplanted from different habitats has different Pn values (Table 1). The maximum values of Pn in a day, contrary to that in the field, for the plants transplanted from different habitats are in order of Xiaotianchi plot >Tree line plot >Tianwenfeng plot (Yan *et al.* 1999). There existed difference in the maximum value of Pn for the plants from different habitats, but not significant.

Table 1. Net photosynthesis rate of *Rh. sachalinensis* transplanted from different habitats

Habitat type	Net photosynthesis rate /μmol CO_2·m^{-2}·s^{-1}		Diurnal accumulation of Pn /mmol CO_2·m^{-2}·s^{-1}
	Diurnal mean value	Maximal value	
Xiaotianchi plot	1.439±0.780	7.981	42.161
Tree line plot	3.195±0.851	7.423	108.765
Tianwenfeng plot	4.542±0.665	6.597	136.752

The diurnal mean value of Pn showed a contrary change trend, comparing to the maximum value. The order for diurnal mean value is Tianwenfeng plot > Tree line plot > Xiaotianchi plot and difference among the three plots is significant. This result is similar to that measured in the field conditions. The diurnal accumulative value of Pn was calculated from quadrating curve of diurnal change of Pn to time. It can more effectively represent photosynthetic capacity of whole plant than instantaneous Pn. Table 1 shows that the diurnal accumulation of Pn for the plant transplanted from Tianwenfeng plot is much higher than that from Tree line plot. And the plant from Tree line plot is also higher than that from Xiaotianchi plot markedly. From these results, we can conclude that characteristic of photosynthesis of *Rh. sachalinensis* transplanted from different altitudes in Changbai Mountain is different, even though the morphological characteristic tends to similarity. Obviously, the transplanted *Rh. sachalinensis* keeps quite a lot of the traits as in the field, but its Pn is lower than that of the field (Yan *et al.* 1999).

Chlorophyll content

From Table 2, we can conclude that chlorophyll content of *Rh. sachalinensis* transplanted from Tianwenfeng plot is higher than those of other two plots. The other two plot are close to each other. The value of Chlorophyll a / b for the plants form Xiaotisanchi and Tree line plots is also approach. Difference in photosynthesis characteristic of transplanted *Rh. sachalinensis* is obvious and as same as chlorophyll content directly displays. This is most likely related to the enzymatic system of photosynthesis that is controlled by the genetic factor.

Table 2. Chlorophyll content of *Rh. sachalinensis* transplanted from different habitats

Plot	Chlorophyll content (a + b) (mg·g^{-1} FW)	Chlorophyll a/b
Xiaotianchi	0.650±0.024	1.783±0.125
Tree line	0.662±0.089	1.728±0.163
Tianwenfeng	0.913±0.026	1.671±0.154

Curve of light dependent Pn

It is significant using curve of light dependent Pn to analyze the photosynthetic capacity of plant. Through the curve of light dependent Pn, some important indexes, such as light compensation point, light saturation point, half-light saturation point and Pn under light saturation point, can be calculated, and the apparent quantum yield (AQY) also can be gotten by it. The curve of light dependent Pn is often measured in research of plant photosynthetic capacity (Du *et al* 1988; Yan *et al.* 1998). *Rh. sachalinensis* is a Cras-

sulaceae plant and its metabolism type of carbonic assimilation of photosynthesis belongs to crassulacean acid metabolism (CAM). Photosynthesis response to light density of CAM plant is similar to that of C_4 plant, having no light saturation point. The measured curve of light dependent Pn indicated *Rh. sachalinensis* transplanted from different plots has no light saturation phenomena, even under maximum nature light (Fig. 1).

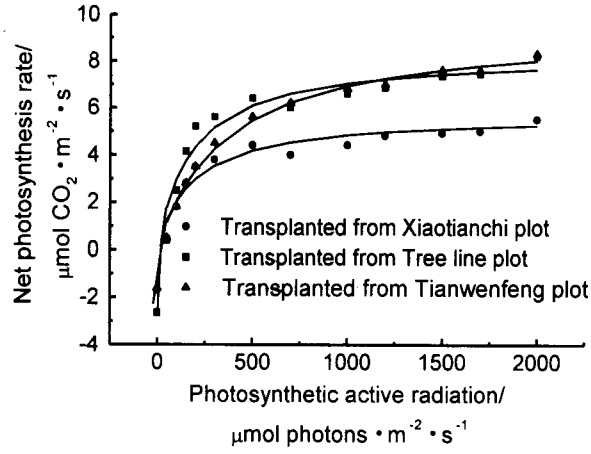

Fig. 1. Curve of light dependent Pn of *Rhodiola sachalinensis* transplanted from Changbai Mountain

The equations derived from fixing three curves of light dependent Pn are as follows:

Xiaotianchi plot, $Pn = 5.708\ I / (184.130 + I)$

Tree line plot, $Pn = 8.321\ I / (184.379 + I)$

Tianwenfeng plot, $Pn = 9.469\ I / (369.538 + I)$

Where Pn is net photosynthesis rate (μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$), I is photosynthetic active radiation (μmol photons $\cdot m^{-2} \cdot s^{-1}$).

According to the curve of light dependent Pn, the light compensation point, Pn under light saturation and AQY of *Rh. sachalinensis* transplanted from different plots were calculated and listed in Table 3.

Light compensation point of the plants from different habitats is in order of Tianwenfeng plot > Tree line plot > Xiaotianchi plot, but there is no significant difference because all their values are low. For the maximum value of Pn, the plants from Xiaotianchi plot is much lower than that from Tree line plot and Tianwenfeng plot. The latter two are close to each other.

AQY refers to assimilative quantity of CO_2 when plant receives unit quantity light. In practice, it often represents a rate of plant releasing oxygen under light or a rate of CO_2 assimilation, namely the ratio of Pn to photon flux density (PFD) correspondingly. When being measured under low PFD (generally 50~150 μmol photons $\cdot m^{-2} \cdot s^{-1}$, means no surplus photon to be left), AQY will be manifested as maximum apparent quantum yield (Von Caemmerer and Farquhar 1981; Xu 1988; Shen 1992; Zhang *et al* 1995). Here, the initial slop of curve of light dependent of Pn is taken as AQY, also as the maximum apparent quantum yield. AQY reflects to a certain extent CO_2 assimilation capacity of plant photosynthetic organ by making use of light energy under measurement condition, that is to say, reflecting photosynthetic capacity. The AQY values of *Rh. sachalinensis* in different habitats in field are in order of Xiaotianchi plot > Tree line plot > Tianwenfeng plot (Yan *et al* 1999). However, for the transplanted *Rh. sachalinensis*, the AQY value of the plant from Xiaotianchi plot was lower than that of in field condition, while that of those transplanted from Tree line plot and Tianwenfeng plot were higher than that of in field condition (Table 3).

Table 3. Characteristic of curve of light dependent Pn of *Rh. sachalinensis* transplanted from different habitats

Plot	Light compensation point /μmol photons·m^{-2}·s^{-1}	Max. Pn /μmol CO_2·m^{-2}·s^{-1}	AQY /mmol CO_2·mol^{-1} photons
Xiaotianchi	18.1	5.574	17.4
Tree line	23.6	8.213	25.1
Tianwenfeng	29.0	8.396	19.3

Respiration rate

Dark respiration rate (Res) of *Rh. sachalinensis* transplanted from different habitats under dark was measured under the same growth condition. The result showed that there existed difference in Res among the three habitats. Diurnal mean values of Res of the plants transplanted from Tree line plot was close to that of the plants from Tianwenfeng plot and much higher than that of the plants from Xiaotianchi plot. The maximum value of Res for transplanted *Rh. sachalinensis*, which occurs at 11:00 around, is Tianwenfeng plot > Tree line plot > Xiaotianchi plot (Table 4). Comparison on Res between field and transplanted cultivation was not made because lacking of field

Characteristic of water physiology

The transpiration rate (Tr) of the transplanted *Rh. sachalinensis* changed with different habitats. The plants from Tianwenfeng plot had the highest Tr in diurnal mean values, followed by those from Tree line

plot and Xiaotianchi plot. Tr value of Tianwenfeng plot is three times that of Xiaotianchi plot. The maximal value of Tr has a same change trend with the diurnal mean value. The maximum values of Tr of the plants from Xiaotianchi and Tree line plots were very close, but about half less than that of the plants from Tianwenfeng plot (Table 5).
data.

Table 4. Respiration rate of transplanted *Rh. sachalinensis*

Plot	Diurnal mean value (μmol CO_2 m^{-2} s^{-1})	Maximal value (μmol CO_2 m^{-2} s^{-1})
Xiaotianchi	1.017±0.163	1.725
Tree line	1.633±0.239	2.642
Tianwenfeng	1.590±0.322	3.316

Table 5. Transpiration rate and water use efficiency of transplanted *Rh. sachalinensis*

Plot	Transpiration rate (mmol $H_2O \cdot m^{-2} \cdot s^{-1}$)		Water use efficiency (mmol $CO_2 \cdot mol^{-1}H_2O$)	
	Diurnal mean value	Maximum value	Diurnal mean value	Maximum value
Xiaotianchi	0.608±0.153	1.753	2.272±0.622	4.846
Tree line	1.069±0.181	1.885	2.775±0.361	4.051
Tianwenfeng	1.958±0.331	3.627	2.266±0.383	4.157

Xiaotianchi area is a relative special habitat. The airflow in this habitat is relatively small due to the shielding effect of *Betula ermanii* forest. A great deal of vapor from the warm spring near to Xiaotianchi plot, makes the air relative humidity of the area be higher. All these result into the Tr value of *Rh. sachalinensis* in Xiaotianchi plot is relatively small, only about one-tenth of that in Tianwenfeng plot (Yan *et al* 1999). However, Tr of the transplanted *Rh. sachalinensis* from Xiaotianchi plot increased a lot, about three times that in the field, while the Tr of transplanted plants from Tree line plot and Tianwenfeng plot were in agreement to that in the field relatively.

Water use efficiency (WUE) listed in Table 5 are not as same as that of crop production affected by irrigation or precipitation in agriculture. It refers to assimilation quantity of CO_2 when the plant transpires unit quantity water, namely, rate of Pn and Tr (Yan *et al* 1990). Since WUE embodies harmonization course of photosynthesis and transpiration inner plant while acclimatizing to exterior environment, we can analyze the relations between photosynthesis and transpiration by it. In the field, WUE of *Rh. sachalinensis* in Xiaotianchi plot is higher (about 3.5 times) conspicuously than that in Tree line plot and Tianwenfeng plot (Yan *et al* 1999). With respect of diurnal mean value, WUE values of *Rh. sachalinensis* transplanted from Xiaotianchi plot and Tianwenfeng plot were approach to each other, but a little bit lower than that from Tree line plot, There is no significant difference in WUE for the three different habitats. Viewing with the maximum value, the plants from Xiaotianchi plot had the highest WUE among three plots, but no significant difference comparing with those from other two plots. WUE values of the transplanted plants from three plots are all lower than that growing in the field. The plant transplanted from Xiaotianchi plot is just only one-sixth of that in the field.

Discussion

Rh. sachalinensis is a typical alpine plant. It had formed its special morphological and physiological characteristics adapted to alpine habitat during long-term evolution. In north slop of Changbai Mountain, the habitats selected for research are different greatly, and growth statue of *Rh. sachalinensis* also varied conspicuously. Xiaotianchi plot located in high grass--*Betula ermanii* forest near to Xiaotianchi lake at altitude 1 800 m. *Betula ermanii* forest with moderate canopy density has heavy shadowy to herbs. Individual of *Rh. Sachalinensis* growing in the site with low density of herbs is delicate, slender, darkgreen and has flimsy leaves. In the Tree line plot, located at the cleugh of Tree line (tree limit), about 500 m from roadside at altitude 2 000 m, there were few tall trees, only a few *Betula ermanii*, and dominant species are *Rhododendron chrysanthum* and *Vaccinium uliginosum*. There is abundant water in soil and soil horizon is deep in this plot. The individual of *Rh. sachalinensis* is tall and has few branches of rhizome. Tianwenfeng plot located in alpine tundra under Tianwenfeng peak at altitude 2 325 m. This plot has strong solar radiation, heavy wind and great evaporation capacity. *Pedicularis verticillata* community is a main type of vegetation in this plot. The individual of *Rh. sachalinensis* here is dwarfish. Its leaf is thick and shows light green. Gas exchange of *Rh. sachalinensis* in the three plots is different obviously. The Pn and Tr, values of the plants in Tianwenfeng plot are the highest, those in Tree line plot are middle, and those in Xiaotianchi plot are the lowest (Yan *et al* 1999).

Photosynthesis and respiration of plant are influenced easily by environment. So it is difficult to distinguish whether the difference of Pn and Tr existed among the individuals of *Rh. sachalinensis* living in different habitats is result from genetic difference of

physiological characteristic of plant itself or environment factors. The results showed that photosynthetic and transpiration characteristic of the *Rh. Sachalinensis* still keep the ways that exhibits in the field after transplanted from different habitats to the same growth conditions. The difference of Pn and Tr existed in the individuals of *Rh. sachalinensis* transplanted from different habitats is depend not only on the environmental factors, but also on the variance of physiological characteristic of plant itself. Though growth status of transplanted *Rh. sachalinensis* have trended to identical and chlorophyll content also shows no great difference, the photosynthetic and transpiration characteristic are still different. This indicated that the transplanted *Rh. sachalinensis* still keeps the traits in the field in photosynthetic carbonic metabolism, including enzyme system and its regulating and controlling course.

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